

IX.—*On the Physical Geography of the Great Indian Desert with especial reference to the former Existence of the Sea in the Indus Valley; and on the Origin and Mode of Formation of the Sand-hills.*—By W. T. BLANFORD, F. R. S.

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§ 1. *Introduction.*—*Geological distinction between the Indian Peninsula and the neighbouring portions of Asia.*—There is no tract of country in India more singular in its character than that which is commonly known as the Great Desert, lying on the eastern side of the Indus between Sind and Rájputana. The peculiar nature of the region has often been described, but there are still some points in its physical geography which appear to require explanation, and which are not, I think, entirely cleared up in the best account of the region with which I am acquainted, that given by Sir H. B. E. Frere in the Journal of the Royal Geographical Society for 1870, Vol. XL, p. 181. To these points, which chiefly refer to the origin of the sand-hills, I shall advert in the sequel.

The physical geography of a country is always intimately connected with its geological construction and history, and from this point of view the Great Desert is a tract of peculiar interest. It is almost a truism at the present day to state that India proper has no geological connexion with the surrounding countries. The whole geological history of the Indian peninsula, from the date of the earliest sedimentary formations, shews scarcely a trace of similarity to that of the Himalayas* or the countries west of the Indus or east of the Bay of Bengal. Wherever remains of sedimentary beds are found throughout the peninsula, of any age from the

* The only exception of any importance is the occurrence of Damuda rocks in Sikkim and Assam.

dawn of organized life to the present day, they consist with but few and local exceptions of rocks which have been formed, in all probability, on the surface of the land; the only case of a marine formation known to exist at a distance of more than 100 miles from the present coast being that of the thin Cretaceous band at Bágh, Barwai, and elsewhere in the western part of the Narbadda valley. On the other side of the great alluvial plain formed by the Indus and Ganges all is different. Marine rocks of various ages form the hills of Sind and the Panjáb, the greater portion of the Himalayas and Tibet (so far as the mountains do not consist of metamorphic rocks), the ranges south of the Assam valley, and the hills of Arrakan and Burmah. Only the later tertiary deposits in Sind, the Panjáb, Northern India, Assam, and Burmah are, as a rule, of subaërial origin and accumulated by the action of fresh water, whilst in Sind there is distinct evidence that the sea covered the greater portion, and very probably the whole, of the country as late as the Miocene epoch.*

§ 2. *Zoological Relations between India and Africa.*—The curious points of connexion between the existing fauna of India and that of Africa and the Mascarene islands bear out the idea of India having formed in past times a portion of a great tropical continent. There also seems a probability, as might have been anticipated, that at different geological periods the distribution of land in this continental area varied, and that different portions were in union with each other. Leaving aside the remarkable evidence afforded by the Mesozoic (and Upper Palæozoic?) floras, amongst which identical species have been found in Australia, Southern Africa, and India, there appear to have been three distinct Tertiary and recent migrations of African types into India, or perhaps it would be more correct to say, that animals having affinities with those now inhabiting Africa have entered India in three different groups, two of which are older immigrants than the other. The first consists of the types common to the Malay countries, India, and Africa, which form a very large proportion of the fauna: such as certain monkeys and lemurs, the *Tragulidæ*, *Viverræ*, *Herpestes*, *Manis*, and *Nectarinidæ*, *Dicruridæ*, *Oriolidæ*, *Pittidæ*, *Bucerotidæ*, *Ploceinæ*, *Megalaiminæ*, &c., &c., &c., *Varanidæ*, *Agamidæ*, &c.† As a rule the African and Indian genera are distinct, but exceptions occur, as in *Viverra*, *Herpestes*, *Manis*, *Zosterops*, *Varanus*, &c. Many of these forms extend to Australia.

The second group consists of forms common to India and Africa but not found east of the Bay of Bengal nor yet in Arabia or Persia, such as *Antilopidæ* (exclusive of *Gazella*), *Mellivora*, *Chicquera*, *Sypheotides* (= *Lissotis*),

* Records Geol. Surv. Ind. IX, p. 15.

† See for fuller details 'Africa-Indien' by A. v. Pelzeln in Verh. Zool.-Bot. Ges. Wien, 1875, p. 33.

Rhinoptilus, the family *Cyclostomidæ*, &c. With many of these the genera are different in India and Africa, though less frequently than in the first case, or, which is more to the purpose (for genera are often artificial, and depend upon human fancy quite as much as natural laws), the amount of divergence is less. The third group comprises forms which are found in Northern Africa Arabia, Persia, and India, but which do not extend to the Malay countries, such as *Hyæna striata*, *Canis aureus*, *Felis leo*, *F. jubata*, *F. chaus*, *Gazella*, *Gerbillus*, *Pterocles*, *Pyrrhulauda*, *Cursorius*, *Saxicola*, &c. In this case the genera and very often the species are identical. Many of the forms are also found in the neighbouring portions of the boreal or palæartic region, and their number diminishes in India itself to the eastward and southward, whilst but few are found in forest. The forms belonging to this category appear to be recent immigrants.

§ 3. *The Indo-gangetic Plain between India and the adjoining regions of Asia*.—Thus both from geological and zoological evidence we have reason to conclude that the union of the Indian Peninsula with Central and South-western Asia is of comparatively late date, and it becomes a question of great interest to ascertain so far as possible the evidence of their own condition in the later geological epochs afforded by the tracts of flat country intervening between the peninsular area and the surrounding regions. These tracts consist chiefly of the great plains through which the Ganges and Indus flow to the sea, and the surface is covered to so great a depth by alluvial deposits from those rivers and their tributaries that very few traces can be found of the geological history of the country. It has been assumed by some writers that this great plain remained part of the sea long after the Himalayas had been elevated. This is not impossible, but so far as the Gangetic area is concerned I fail to see that there is evidence in favour of the view; and I think the idea is mainly due to the Pliocene Sevalik deposits having frequently been considered marine, whilst it is more probable that they are really of freshwater and probably subærial origin, for not a single marine organism has been detected in them, whilst freshwater shells have been found in them in places. Even without entering into the question as to whether the whole Indo-gangetic plain has been covered by the sea in late geological times, the question arises whether the Indus plain, in which we have the latest evidence of marine life, has been thus covered. This is a speculation of Mr. Andrew Murray, proposed to account for the presence of a dolphin in the Indus and Ganges, and for the difference of the species inhabiting each.*

* *Geographical Distribution of Mammals*, p. 214. Mr. Murray's theory is briefly the following. The dolphin inhabited an arm of the sea which became a lake through the rise of land, and which was gradually rendered fresh by streams falling into it and cutting their way to the sea, first in the direction of the Ganges, secondly through

During a recent traverse of the desert, I have tried to find evidence of its condition in late geological times, and although the result is mainly negative, some facts appear to point to a recent condition of things when the sea did flow some distance up the Indus valley. At the same time I have not met with any evidence in favour of the view that the great plain of the desert has recently emerged from the sea. The route followed was from the Indus near Sehwan, viâ Umarmot in the Thar and Parkar district of Sind, to Bâlmîr, and thence to Jodhpûr in Râjputana, returning from Jodhpûr, viâ Jaysalmîr, to Rohri on the Indus.

§ 4. *Physical Characters of the Desert. Botany and Zoology.*—It is as well before entering further into the subject to point out the chief peculiarities of the Great Desert. The term conveys an imperfect idea, because the tract of country is neither barren nor uninhabited; it is covered with shrubs and bushes in general, and in places small trees are found; moreover, although the population is thin, villages are scattered throughout, and immense herds of camels, cattle, sheep, and goats are kept and pastured. The desert is, in fact, a great sandy tract entirely destitute of streams of water, and with but few hills of rock, and a large portion of the surface consists of sand-hills of considerable height and is known locally as Thar (Thurr). When rain falls, crops of bājri (*Holcus spica*) are raised. When rains fail, the population lives principally on the milk of cattle and on imported grain.

Throughout the sandy tracts the vegetation* consists mainly of four plants known as *Phog* (Sindhî *Tob*) (*Calligonum polygonoides*), *Bhûi* (Sindhî *Bakûsa*) (*Aerva Javanica*), *Lâna* (*Anabasis multiflora*), and *Mart*, a coarse grass growing in tufts. *Lâna*, although very common in some places, is rare or wanting throughout large tracts. *Phog* and *Bhûi* are peculiar to the sand-hills themselves; *Mart*, besides abounding on the sand-hills, covers the large sandy plains, which in many parts extend for miles. It is a coarse grass with a hard woody stem, and appears to be one of the principal plants eaten by cattle and horses. Another common plant on the sand-hills is *Kîp* (*Orthanthera viminea*). Between the sand-hills *Madâr* (*Calotropis procera*), *Pilû* (Sindhî *Kabar* or *jâr*) (*Salvadora Persica*), *Kejri* (*Acacia rupestris* ?), *Kiril* (*Capparis aphylla*), *Ber* (*Zizyphus jujuba*), and a few other plants are com-

the Indus after the Ganges had been cut off from the lake by another rise of land. He considers that by this means a marine dolphin has become converted into *Platanista* and then the animal has been transferred to the second river after being cut off from the first. The question of the origin of *Platanista* it is unnecessary to discuss; the migration of the original form from one river to the other has probably been due to some of the tributary streams, such as the Satej or Jamna, being transferred from one drainage-area to the other. This would be effected by a very trifling change of level.

* I am indebted to Dr. King for the identification of these plants; of some, as *Mart*, I unfortunately did not take specimens.

monly found. After rain it is said that numerous herbs spring up, and a grass called *Brút* (? *Centhrus biflorus*), the spiny seeds of which have a most unpleasant habit of attaching themselves to one's clothes like burs. These seeds, divested of their spiny covering, are used for food, and are made into a kind of bread.

As might be anticipated, the desert fauna is poor, and in the sandy tracts is entirely confined to animals which never require water. Hyænas are met with in the more hilly parts but not, I think, amongst the sand-hills; wolves (*Canis pallipes*) and jackals are more common. The only carnivorous animal, however, which is universally found, is the desert fox (*Vulpes leucopus*); *V. Bengalensis* is also met with, but less abundantly. The caracal (*Lynx caracal*) is said to be common, but the only wild cat I saw was, I believe, *Felis torquata*, and I never succeeded in shooting one. None of the larger carnivora are found, though a leopard may occasionally straggle across to the hills of Bálmír or Jaysalmír. The mammal of the desert *par excellence* is the desert jerboa-rat (*Gerbillus Hurriane**), which exists in almost incredible numbers, the whole surface of the sand-hills being dotted over with the entrances to its burrows. Over thousands of square miles, the number of burrows probably exceeds on an average one to every square yard. There can scarcely be a doubt that this little animal—which is a pretty little creature of a greyish tawny colour, with rather long hind legs, a rounded head, and a long hairy tail—would in most countries furnish an important item of food, for it is purely herbivorous, living chiefly on seeds and roots. Besides furnishing food to the foxes and wild cats, this rat is the prey of buzzards and of many of the other raptorial birds. No other rodent is found in the sand-hills; I did not even see a hare, though the Sind representative of the genus (*Lepus Dayanus*) is common in the hilly tracts, whilst the only ungulate found in the Thar is the Indian gazelle (*Gazella Bennetti*).

Thus it may be said that the only common mammals of the sand-hills are the fox, gerbil, and gazelle, and all these, I believe, can live without drinking. I am certain that the two latter never drink. The birds are more numerous. The common falcon is *F. jugger*, but I believe I saw *F. sacer* also. *Aquila fulvescens* abounds in places and I met with *Circæëtus gallicus* occasionally. But the most common raptores are the desert buzzard (*Buteo ferox*) and kestrels. Vultures, Neophrons, and kites are chiefly seen about villages. Owls are not common: I twice came across flocks of the short-eared owl (*Otus brachyotus*), and I occasionally found *Athene Brahma* and once *Scops Brucei*.

The bee-eater (*Merops viridis*) is found generally distributed. Swallows are occasionally seen; swifts (*Cypselus affinis*) are very local as usual. Goat-

* *G. erythrourus*, Gray, *apud* Jerdon, but true *G. erythrourus* is a different species, Zool. Persia, p. 70.

suckers are extremely rare. Shrikes are represented by *Lanius lahtora*, which is common and the only species noticed amongst the sand-hills. *Dicrurus albirictus*, the common king-crow, is found everywhere, and two bulbuls (*Otocompsa leucotis* and *Pycnonotus pusillus*) are occasionally met with, the latter, contrary to what might have been expected, inhabiting the sand-hills quite as often as the former, if indeed it be not the commoner form. The striated babbler (*Chatorhea caudata*) is very abundant everywhere. *Franklinia Buchanani* is not uncommon. *Drymæca gracilis* is rare. *Sylvia curruca* is frequently seen, but both *S. Jerdoni* and *S. nana* are of exceptional occurrence. The *Phylloscopi* are of course very rare in this treeless region. The common *Saxicola* is *S. picta* throughout the whole desert; *S. deserti* is not rare, but *S. isabellina*, so abundant in parts of Sind, keeps as usual to the more fertile tracts. I saw *S. chrysopygia* occasionally, and it was more common about the middle of March, when like other *Saxicolæ* it was migrating to the north. *S. opistholeuca* and *S. morio* I only noticed about Jodhpûr or between that town and Jaysalmîr. *Pratincola Indica* (v. *rubicola*) was occasionally seen even amongst the sand-hills, *P. caprata* only in the more fertile tracts. *Thamnobia Cambayensis* was generally met with throughout the region. A stray *Motacilla alba* or *Budytes melanocephalus* was now and then seen near wells, and the pipits were poorly represented by the occasional occurrence of *Anthus campestris* and *A. sordidus*.*

Larks are more abundant and the commonest species by far is the finch-lark, *Pyrrhulanda melanauchen* (*P. affinis*, Blyth), the very existence of which in India was scarcely known until quite recently. I was surprised to find *Mirafra erythroptera* by no means uncommon in the Thar, although it is unknown in Sind. *Galerita cristata*, *Melanocorypha bimaculata*, and *Calandrella brachydactyla* are also found, the two latter in flocks. The first is common, the other two far from rare. *Passer indicus* occurs everywhere of course, though preferring the neighbourhood of cultivation. *Gymnoris flavicollis* is usually found where there are trees. I once or twice saw *Emberiza Huttoni*, but *E. striolata* is found on all rocky hills. *Munia Malabarica* is common. Ravens (*Corvus corax*) are seen everywhere, the two common crows (*C. Vaillantii* and *C. impudicus*) only about cultivation. *Pastor roseus* is occasionally common, even amongst the sand-hills, but the two forms of maina (*Acridotheres tristis* and *A. ginginianus*) are only seen about villages. Doves are represented by *Turtur Cambayensis* and *T. risorius*, common everywhere, whilst the common wild pigeon (*Columba intermedia*) breeds in all wells. On the sand-hills I saw no sand-grouse; they only occur where water is procurable, but they occasionally drink at wells: the only common species is *Pterocles exustus*, but *P. arena-*

* *A. Jerdoni*, Finsch, *A. griseo-rufescens*, Hume. I find Mr. Blyth was right in uniting the Indian bird with the African form.

vius and *P. Senegallus* are met with in places. The grey partridge (*Ortygornis Pondiceriana*) is found everywhere, whilst the cream-coloured courser (*Cursorius gallicus*) and the Indian bustard (*Eupodotis Edwardsi*) are pretty generally distributed.

The common birds in the Thar are *Falco jugger*, *Tinnunculus alaudarius*, *Buteo ferox*, *Merops viridis*, *Pycnonotus pusillus*, *Lanius lahtora*, *Dicrurus albirictus*, *Chatorhea caudata*, *Sylvia curruca*, *Saxicola picata*, *Thamnobia Cambayensis*, *Pyrrhulauda melanauchen*, *Galerita cristata*, *Passer Indicus*, *Munia Malabarica*, *Corvus corax*, *Turtur Cambayensis*, *T. risorius*, and *Ortygornis Pondiceriana*.

The only common reptiles are lizards and they appear for the most part to hibernate in the cold season. The most abundant is *Acanthodactylus Cantoris*; I also found *Agama agilis* very common between Jaysalmír and Rohri. In the same district peculiar vermiform tracks abounded of a small lizard which I have no doubt is *Sphenocephalus tridactylus*, but this animal is nocturnal and a burrower, and although I often searched for it, I never succeeded in finding it. On more rocky ground I found *Ophiops Jerdoni* and *Mesalina pardalis*. The only harmless snakes which I saw were forms of *Zamenis* and *Psammophis*, and the only venomous species was *Echis carinatus*. No tortoises were seen or heard of.

§ 5. *Distribution of the Sand-hills.*—The sand-hills have a somewhat peculiar distribution. They occupy a large tract in Eastern Sind, extending the whole length of the province, along the edge of the Indus alluvium. Here they are close together and form long ridges, running nearly north-east and south-west near Umarmot, and about north-north-east to south-south-west near Rohri.* In the southern portion of the desert, they are said by Sir B. Frere to run nearly east and west. They are much higher to the southward than to the north, but I saw none approaching the heights of 400 to 500 feet, said by Sir Bartle Frere to be common in parts of the desert.† The highest sand-hills which I observed near Umarmot, cannot, I think, have exceeded 200 feet, but I did not measure them, so I may be in error. This tract on the borders of Sind is the "Thar"—a name which is, in the country, restricted to the sand-hill region. From the Sind frontier to Bálmir, although there are many sand-hills, they are far from being as generally distributed as they are to the westward, whilst east of Bálmir they are, for some distance, only dotted over the surface, but they again become more general before reaching the Lúni river, and the hills, in this direction, appear to form part of a sand-hill tract which stretches to the northward

* The change in direction is shewn on the revenue survey map, on which the general course of the ridges is indicated.

† I was told that the highest sand-hills are found more to the southward between Umarmot and the Ran of Kachh.

or rather to north-north-east in the direction of Bikanír. The hills in this tract are not in such regular ridges as they are to the westward, but here also they appear to diminish in height and to become more scattered to the north. Between Jodhpúr and Pokarn this eastern belt of sand-hills is only about 40 miles broad. From some distance east of Pokarn to Jaysalmír, and again for 50 miles west of Jaysalmír, the country is an undulating sandy plain, but there are very few sand-hills. I have no personal knowledge of the desert north of Jaysalmír. Stripped of the sand-hills the country would be a vast plain, slightly elevated above the sea, and only broken by isolated hills to the southward, by the somewhat more numerous ranges near Bál-mír, by low plateaux of sandstone towards Jodhpúr and Pokarn, and by terraces of Jurassic sandstone and limestone around Jaysalmír. The hilly regions are less sandy; occasionally even torrent-beds are found near the hills, but they are soon lost in the sand.

§ 6. *Evidence of subrecent Marine Action. Salt 'dhandhs.'*—It is impossible for any geologist to traverse this region without the suggestion forcing itself upon him that this may be an example of Professor Ramsay's planes of marine denudation. Such was my first impression. But I could only find one circumstance, the general saltiness of the ground, in confirmation of this view. Every here and there throughout the desert is a smaller or larger plain of salt ground or "ran", which is said to become a shallow salt lake after heavy rain. From such places salt is sometimes extracted, but the quantity is small, and not more than might, very possibly, result from the gradual concentration of the salt distributed in small quantities throughout the soil. The water in the wells is very often brackish, but this is equally the case in countries which shew no trace of having been recently covered by sea water. There is, however, a very remarkable quantity of salt in two localities which I visited, and in one of them there is, I think, good evidence of the former neighbourhood of the sea.

To take the more important and the more interesting first. North of Umarkot the boundary of the Indus alluvium and of the Thar or sand-hill area is formed by a river known as the Narra or the Eastern Narra,* which derives its water from floods in Baháwalpúr and the Rohrí district of Sind, and has of late years been artificially supplied by a canal cut from the Indus at Rohrí. On the east of the Narra rise high ridges of sand with the usual NE to SW direction, and between these ridges are deep valleys filled with water and known as 'dhandhs.† Some of these 'dhandhs' are said to be unfathomable;—and doubtless they are so by an ordinary pole

* The Sindhi form, I believe, of the common Hindi *Nala*, a river channel, ravine, or ditch.

† *Dhandh* in Sindhi is the equivalent of *jhíl* in Hindi and is applied to any pool of water or to a marsh.

or bamboo, the only instrument likely to have been used in general for sounding. Sir Bartle Frere says that he has been assured that the depth of one has been measured and found to be 70 feet.* This shows of course considerable depression below the level of the Indus alluvial plain, for the Narra, which must of course be a little below the average level of the plain, supplies, or used to supply, the water for the 'dhandhs' in its immediate neighbourhood.

There are, however, a large number of small lakes isolated amongst the sand-hills and not in communication with the 'dhandhs' fed by the Narra, and these isolated lakes are all salt; those farthest from the Narra being apparently the most saline, and some being so concentrated that salt crystallizes on their margins. All these salt 'dhandhs' appeared to me to be at a lower level than the freshwater lakes, and this view was confirmed by my finding that small streams fed by springs amongst the sand-hills enter in many cases at the western edge of the salt 'dhandhs', and that where, as not unfrequently happens, there are more than one 'dhandh' in the same hollow, a stream often flows from the western pool to that lying more to the eastward. Now the water can only be derived by percolation through the sand from the freshwater 'dhandhs' to the westward: it is true that springs often rise from the margin of the latter, and that these springs are sometimes above the surface of the lakes, but they are usually below, and if higher they are not so far above as in the case of the salt lakes to the eastward, on the edge of which I found springs issuing from the ground 15 or 20 feet above the water.† It is a natural conclusion that the original surface of the ground at this spot was not higher than the bottom of the 'dhandhs' are now, that it was much lower than the present alluvium of the Indus, and that the Indus plain has been raised to its present height by the accumulated silt deposited from the river since the 'dhandhs' have been cut off and isolated by the sand-hills.

§ 7. *Marine Mollusk living in salt lakes.*—One more observation gave the clue to the original conditions of the ground. I found in some of the salt lakes in which the water, although very salt, was rather less so than that of the ocean, a living mollusk which has been identified by Mr. Nevill with *Potamides (Pirenella) Layardi*, H. Ad. This species inhabits the salt water of back-waters or lagoons and harbours: it is not found to the best of my belief on open coasts, nor yet in the brackish water inside the mouths of rivers, and although, like most other forms of *Potamides*, it is rather

* J. R. G. S. XL, p. 189.

† The springs on the edges of the freshwater dhandhs are doubtless due to the water which percolates into the sand when the dhandhs are at their highest level from floods brought down by the Narra.

estuarine than truly marine, its habitat is always in water nearly if not quite as salt as the sea. The specimens which I obtained are precisely like those now living on the coast of India. Several cases are known of marine animals (chiefly vertebrata or crustacea, however) found living in freshwater, and apparently descended without change from ancestors which inhabited the same tract when it was part of the sea, but it is rarer to meet with a marine or estuarine mollusk living on unchanged in inland salt lakes without an outlet, at a distance of 150 miles from the sea and of 100 miles from the nearest point to which the tide reaches. The conclusion to be drawn from the existence of this mollusk is unmistakable: it must have inhabited the tract now occupied by the sand-hills and their enclosed 'dhandhs' when that tract was in direct communication with the sea, and probably when it formed part of a large lagoon.

§ 8. *Former existence of an Inlet of the Sea in Eastern Sind. The Ran of Kachh.*—Two further conclusions follow as corollaries, the first that the saltness of the soil or subsoil is due to this tract of country having been the bed of the sea, or of an inlet, the second that the sand-hills must have been formed on the margin of the lagoon, and that probably the lagoon was partly filled up and isolated by accumulations of blown sand.

About 100 miles to the south of Umarnkot lies the Ran of Kachh, an immense salt plain covered by salt water when the sea, driven up into it by the south-west monsoon, ponds back the more or less brackish water brought down by the Lúni and the few streams which run in from the hills of Kachh. Various theories have been proposed to account for the Ran. It is commonly considered an area of upheaval, a raised sea bottom. This is the view taken by Captain Grant and by my friend Mr. Wynne*, although both speak also of its silting up. I had an opportunity of seeing a portion of the Ran in 1863 and I wrote of it (in 1867†) "I am disposed to consider (the Ran) the bed of an inlet of the sea filled up by the accumulation of detritus brought down by the rivers. It is just at present in the debatable state, water part of the year, land another part of course the whole may be an area of depression, but further proofs of this are necessary than the fact of a small portion having been sunk and another part raised by the earthquake of 1819."

It must be borne in mind that there is evidence of slight elevation at several places on the coast of Western India; such has been noticed in Sind, Káthiáwád, and on the borders of the Ran itself, and the area of the Ran has doubtless shared in the general rise. So far I agree with other observers; but if I understand them correctly, I infer that they rather regard the Ran as an area of special upheaval, and in this I cannot concur.

* *Memoirs Geol. Surv. India*, IX, pp. 21, 28.

† *Ibid.* VI, p. 31.

The probability is that Kachh was originally an island*, and the Ran a vast inlet of the sea, which gradually became shallow, just as other inlets on the coast of India, *e. g.* Bombay harbour, are gradually being filled up by silt deposited from rivers, aided, in the case of the Ran, by blown sand and also by the gradual elevation of the whole area, and (which is the most important point in the present discussion) that this inlet extended into the region now forming Eastern Sind to a distance of at least 100 miles and probably much further. I have no precise information as to the distance to which the salt 'dhandhs' extend to the northward, but they are certainly found in the Khairpúr territory, and I find one marked on the map in Rohri, whilst there is a tract of country between Jaysalmír and Rohri in which wells of freshwater are excessively scarce and local. West of Umarmót the wells are brackish for about 35 miles; further east than this rock is found in the wells and the water is sweet. The spot where the change takes place may mark the limit of the former inlet.

§ 9. *The Lúni Basin.*—We thus have proof that an arm of the sea ran for a considerable distance up the Indus valley in very late geological times, although it is not yet manifest how far it extended, and the question arises whether there is any reason for inferring the former existence of the sea in any other part of the desert area. I have already mentioned a second locality which I had an opportunity of examining, and where salt is found in large quantities. This is near a town called Panchbhadrá, a short distance north of the Lúni river and about 45 miles south-west of Jodhpúr. Here salt is largely manufactured in a slightly depressed tract of country, which may formerly have been the bed of a salt lake, but is now surrounded and partly covered by drift sand. Salt must abound throughout the lower course of the Lúni, for the water of the stream in the dry season is very strongly impregnated. It is not merely brackish, it is decidedly salt. The fall of the river is said to be very small, but of this I had no means of judging personally. If it be the fact, the river's course below Panchbhadrá may very possibly have been an arm of the sea in recent times.

It is impossible to avoid speculating on the origin of the salt in the Sámbar lake being also connected with the former extension of the sea.

§ 10. *Want of evidence of Marine Denudation elsewhere in the Desert.*—Apart from the evidence afforded by the abundance of salt and the remarkable existence of a marine shell in the salt 'dhandhs' of the Thar, I searched in vain for evidence of recent marine action in the desert. The general flatness of the area may be due to marine denudation, but it may also be due to the extreme flatness of the rocks and the absence of disturbance.

* The distribution of the Tertiary rocks in Kachh is quite consistent with the view that this tract formed an island in Eocene times, when we know that the Indus valley, Balúchistán, and Southern Persia were beneath the sea.

Except near Bálmír, where there are some craggy hills of ancient formations, and where the sandstones of Mesozoic age resting upon the older rocks dip at high angles, the sedimentary beds found preserve almost perfect horizontality. The low cliffs of sandstone near Jodhpúr, and those of sandstone and limestone near Jaysalmír, are palpably scarps of subaërial denudation, for they correspond precisely, over miles of country, to the outcrop of the harder beds; nowhere is a characteristic marine cliff, cutting through different strata, to be met with, nor is there any evidence of marine action, so far as I can see, around the isolated hills of Bálmír. Whilst therefore there is a probability that the sea did extend up the Indus valley and a possibility that it may have stretched up the Lúni basin, and from one side or the other have reached the Sámbar salt lake, there is no evidence that it covered in recent times the central area of the desert about Bálmír and Jaysalmír.

§ 11. *Nature and Origin of the Sand-hills.*—I have already described the general distribution of the sand-hills, and I have said that I am unable to coincide with Sir Bartle Frere's views as to their origin. He compares them to the ridges of rock found in Sind, and suggests that they may be due to earthquake-action. He points out that the Allah Bund, which is known to have been caused by an earthquake, is "a perfect outlying specimen of a typical Thar sand billow of moderate height", and he discusses the mode of formation of sand-ridges by the wind and gives his reasons for believing that the ridges of the Thar are not due to wind-action. To some of these reasons I shall revert presently. Meantime, I think Sir B. Frere has overlooked some phenomena of sand-hill formation. At the same time none of the works I have been able to consult throw any light upon the parallel sand-ridges of the Thar, of which I confess I am unable to offer a satisfactory explanation. I think, however, that there can be no doubt that all are due to wind-action alone, and I will give my reasons after describing the peculiarities presented.

The sand consists chiefly of small grains of quartz, mixed with felspar and hornblend in smaller proportions, other minerals only occasionally occurring. The grains are mostly rounded, precisely as in the sand of rivers or of the coast, and they are tolerably uniform in size.

I have already mentioned that the sand-hills form long ridges, with a very uniform general direction, along the edge of the Indus alluvium, where they are highest, and where the country is completely covered by sand, and that they are less regular in their direction more to the eastward. But there is one character which they preserve in both localities, though it is much more strongly marked to the eastward, and this is a tendency to terminate abruptly with a steep face towards the north-east. The long north-east to south-west ridges have as nearly as possible the same slope on both

sides, but they often end in a higher point at their north-eastern extremities. The scattered hills east of Bálmír are always highest to the north-east and slope away very gradually to the south-west. The sand-hills as a rule are evidently of very great antiquity; they often shew evidence of denudation from the action of rain, and sometimes they are worn into ravines several feet in depth. When it is considered how small the desert rainfall is (11·8 inches in the year at Umarkot, 18 at Nagar Parkar, but much less in the central portion of the desert, and especially towards Jaysalmír), it is evident that a long series of years must be required for ravines even a foot in depth to be cut in the sand, since it is only in exceptionally heavy showers that any water can run off so porous a surface. At the north-eastern termination of these sand-hills, however, there is frequently found a quantity of sand which is shewn to be newly deposited by its surface being ripple-marked, by the absence of holes made by burrowing animals, and by the stems of bushes being partially buried. Lastly, from the north-east corner of most of the high hills near Bálmír a long ridge of sand runs out, evidently deposited by the wind under the lee of the hill.

Now there is one point to which it is necessary to advert before going further. I must apologize for mentioning a fact doubtless familiar to most of my readers, but although familiar with it on a small scale, I did not clearly understand its application when I first went into the desert, and in consequence I was for some time greatly puzzled by the phenomena presented by the sand-hills; I think, too, that it has been overlooked by Sir Bartle Frere, and that this accounts in part for his doubting the efficacy of the wind in producing the sand-hills of the Thar. On the possibility that it may not be universally familiar I will venture to call attention to it.

When the wind blows over any surface composed of particles which can be moved independently, it forms waves or ridges more or less at right angles to its direction, with a long low slope to windward and a steeper slope to leeward. Something similar is seen in sand-banks formed by rivers and must be well-known to all who have navigated any Indian river in the dry season. In descending the stream the depth of water every here and there will be found to diminish gradually up to a certain point, which is part of a shoal stretching more or less across the channel; below this the water becomes suddenly deep. Here again the long gradual slope is on the side from which the current runs, the steep slope in the direction towards which the river is flowing.

This phenomenon on the small scale must be familiar to every one, as it may be seen on sand or dust wherever the wind blows over it. The long slope to windward is variable, the steeper slope to leeward is that assumed naturally by a talus of the material forming the ripples. The sand is driven up the longer windward slope by the wind and

falls over the crest of the ridge.* Sand-dunes along the coast are rendered irregular in shape by accidents of the surface on which they have accumulated, but the laws of their formation are precisely similar to those of the ripples, and the same principles govern the formation of inland sand-hills. The latter are often even more irregular in form than the sand-dunes of the coast, because they are not formed along one general line, but depend on the accidental accumulation of sand wherever the character of the surface is favourable. In every case, however, the direction of the wind to which the drifting of the sand is due is marked by the two slopes in opposite directions, the long slope to windward, the steep slope to leeward. The sand-hills near Bálmir are evidently due to the transport of sand by a south-west wind.

I made many enquiries in the desert country as to the prevailing wind. From all whom I asked I received one answer, that during the hot season, May, June, and July, a strong wind blows steadily from the south-west. Even in March, on two occasions, a violent wind sprang up in the afternoon from that quarter, and the air was so thick with sand that at times it was impossible to see more than a dozen yards. There is no meteorological station fairly within the desert region, but the registers of wind-direction at Karáchí and Dísá shew a great prevalence of south-westerly winds in the hotter months of the year, the general direction being more westerly at Dísá than at Karáchí; up to April the general direction at Dísá is north of west. At other periods of the year the winds are light, and during the months of January, February, and March, when I was in the desert, light breezes from the north or south prevailed alternately, but with the exception of the south-west winds already mentioned, they were quite insufficient to move the sands.

I do not think that further evidence is needed to prove that the formation of sand-hills throughout the eastern part of the desert is due to the south-west winds of the hot season, but there is a much greater difficulty as regards the long north-east to south-west ridges of the Thar. That they are also due to the prevailing winds is apparent from the circumstance (already mentioned) of their frequently terminating in a high bluff with a steep slope to the north-east, but still their general direction, identical with that of the prevailing wind, is rather difficult of explanation, because ridges

* The formation of sand-dunes will be found discussed in any elementary treatise on Physical Geography or Geology. The following works contain excellent descriptions of the phenomena exhibited by blown sand:—Lyell, *Principles*, Vol. I, p. 516; De la Beche, *Geological Observer*, p. 59; Jukes, *Manual*, p. 154; Naumann, *Geognosie*, II, p. 1170; Ansted, *Physical Geography*, p. 467; and especially Marsh, 'Man and Nature,' pp. 471-483, and Reclus, 'The Ocean' (English translation), I, pp. 198-214. I am indebted to my brother Mr. H. F. Blanford for the latter references.

are usually produced at right angles to the wind's direction.* Parallel rows of sand-dunes along a coast are frequently due to the regular sea-breeze, and, as may be seen on the east coast of India, there are often several such rows one behind the other, but they exhibit the usual evidence of their origin by having a long slope towards the sea and a short steep slope landwards. I think it quite possible that the sand-hills of Umarnot and Eastern Sind generally may be of such antiquity as to date from a period when the relative distribution of sea and land in the region was different from what it now is, and that to so great an extent as to completely modify the prevailing winds, and I have even been induced to speculate on the possibility of the existent parallel ridges of sand-hills marking successive coast-lines as the sea receded from the face of the country. This hypothesis, however, would render it necessary to suppose that the Indus valley was a land area whilst the present desert was part of the sea, and that the western coast-line of the sea with a general north-east to south-west direction gradually receded towards the south-east; or, *vice versa*, that the Indus valley was sea, and the country to the south-east dry land. But I can hardly conceive that such gigantic changes as this would involve could have taken place without completely changing the original form of the sand-hills, and it is evident that the ridges in the region of the salt 'dhandhs' must be posterior in date to the time when their present site was part of an inlet of the sea, and not anterior to it. Moreover, had the sand-hills been formed along a coast-line, or even inland at right angles to the prevailing wind, they would, here and there at all events, have preserved some traces of their original slopes shewing the direction of the wind which produced them. But there is nothing of the kind to be found. I looked most carefully for some evidence of a steeper slope on one side than on the other, but without success, and I found double ridges having a trough-like hollow along the crest, with the slopes on both sides of the hollow, as well as those on both sides of the main ridge, equally steep. For such ridges I am quite unable to account by the effect of a wind blowing at right angles to their direction. If they were formed by one great sand-wave overtaking another, one side of the depression between the crests of the two waves must be much steeper than the other, and although this would be slightly modified by time, it could not be entirely obliterated and yet leave the general form of the waves so little altered as they now appear.

I am obliged therefore to reject the theory that these parallel ridges are due to a wind acting at right angles to their direction. I cannot accept Sir Bartle Frere's view that they are due to earthquake-action. The ridges

* Naumann, however, in his 'Geognosie' (edition of 1854, Vol. 11, p. 1171), says—
"The sand-hills themselves are in every country extended in length in one direction which agrees with the direction of the prevailing wind."

consist of the characteristic blown sand ; the Allah Bund, to which Sir Bartle compares them, is only 20 feet high and of great breadth, and consists of the silt which forms the Ran*, whilst even the fact of the elevation being due to the earthquake appears not clearly established. The only alternative conclusion as to the origin of the Thar sand-ridges is that they were due to the wind blowing in the same direction as that in which they lie. Sir B. Frere objects to their origin by the wind that they are higher than any known ridges of blown sand, but I find it recorded that in the Landes of Gascony many dunes exceed the elevation of 225 feet and one attains the height of 391 feet, whilst on the west coast of Africa hills of blown sand are said to be found in the neighbourhood of Cape Verde no less than 600 feet high.†

This view of the sand-ridges having been produced by winds blowing in the same direction is supported by the frequent occurrence (already mentioned) of abrupt terminations of the ridges at their north-eastern extremities. It should be borne in mind that the ridges, although extending for considerable distances, often for some miles, do end or coalesce every here and there, and that there is not any regularity in the size of the valleys that intervene ; some of these valleys being of considerable breadth, others narrow. As a rule, the intervening valleys do not exceed half a mile in breadth where the ridges are tolerably regular, and in many places the hollows are, as a rule, much narrower. Not unfrequently a tract is found where ridge and valley succeed each other with the greatest regularity for a few miles, the valleys being from twice to three times as broad as the ridges.

I am not able to explain the mode of formation of these parallel ridges satisfactorily to myself. I can suggest three modes in which they may have been formed, and I think it possible that all may have acted at times.

The first is the mode of formation from a ridge transverse to the direction of the wind. When such a ridge is driven forward, the ends advance more rapidly than the centre, and a crescent is formed, the convex side to windward. This on a small scale is a common and familiar phenomenon, and is mentioned and explained in all text-books. I can conceive it probable that, with constant supplies of sand, the ends of the crescent may continue to be produced until they form parallel ridges. But I must say I have not seen this change in progress in the sand-hills of the desert.

The second suggestion is that the sand is carried along in lines by the wind. I once came across a tract in which a sand-ridge appeared to be in process of formation. This was about 50 miles W. N. W. of Jaysalmír, at the spot where the Thar or sand-hill country was entered from the undula-

* See Wynne, *Geology of Kutch*, *Memoirs Geological Survey of India*, IX, p. 40.

† Naumann, *Geognosie* ; Reclus, *L'Océan*, ll. c. &c. The latter writer gives Ritter as his authority.

ting sandy plain. Over a breadth of about a quarter of a mile, and right and left, in the direction of the wind, as far as the eye could distinguish, the surface was covered with sand in small newly formed hillocks, mostly of crescentic form and about 5 to 10 feet high. The direction of the wind was shewn to be from S. 35 E., this being at right angles to the lines of ripples, and to the chords of the crescentic arcs formed by the hillocks; and the general direction of the sand-ridges immediately to the westward was the same. Many of these sand-ridges were so regular that it was difficult to conceive that they could have been formed otherwise than in long lines. But I do not quite understand how the wind can thus form them. There is a great difference between forming a line of hillocks and uniting them into one continuous ridge.

The third suggestion is that the tract of country along the edge of the Indus alluvium was originally covered at least as deep as the height of the present sand-hills by sand arranged more or less in ridges at right angles to the prevailing south-west wind, and that the valleys between the present sand-hills are the result of wind-denudation, their contents having been swept away and the intervening ridges left. The abrupt terminations of the ridges mark the former leeward slope of the sand-hills. On the whole, I think this last theory is the most probable of the three.

The sand, it is true, accumulates in long ridges behind any obstacle, and, when a ridge is once found, it will tend to be prolonged to leeward. But no obstacle exists of sufficient size to account for the commencement of a ridge 100 to 200 feet high.

§ 12. *Source of the Sand.*—There is yet one point which demands notice and that is the source of the sand. Rounded sand-grains are rarely produced in any quantity by simple subaërial disintegration, except in the case of the degradation of a sandstone, and in the present instance there is no sandstone area to windward. All the sand may safely be assumed to be derived from river-channels or the sea coast.

Part of the sand may be derived from the bed of the Indus, and probably a large portion of the sand-hills of Rohri are supplied from this source. But it is difficult to conceive that all the sand-hills of Thar and Párkar, Malláni, Jaysalmír, &c., can have derived their sand from the Indus, to say nothing of those of Jodhpúr, Bikanír, &c.

Some of the sand also may be derived from the present coast-line. But all the sand-hills are at a distance from the coast, and it is difficult to conceive that all the sand has been blown across the delta of the Indus and the Ran of Kachh to reach the region where it so greatly abounds. Had all the sand which is spread over the plains of western Rájputána been blown across the Ran, the latter would surely have been converted into a sandy desert long since.

The only remaining conclusion is that the sands are derived from a former coast-line, which no longer exists. The greatest accumulations of sand are found in the lowest portions of the desert, along the edge of the Indus alluvium, and in the basin of the Lúni, and it has already been pointed out that, precisely in these localities, the presence of salt in considerable quantities renders the inference probable that arms of the sea extended into them at a comparatively recent date. Thus both the distribution of salt and the prevalence of sand-hills point to the same conclusions, and it is reasonable to infer that the sea, which, at no remote period, covered the Ran of Kachh, extended for a considerable distance both to the north up the Indus valley and to the north-east up the basin of the Lúni.

In most countries in which sand is blown from river-beds or the sea-coast, it is either blown into other river-channels or it is swept into them by rain. Once in the river-channels it is again carried onward to the sea. There are small sand-hills in abundance in the Indus alluvial plain, but they attain no great size because the sand is always swept sooner or later into some stream. The peculiarity of the desert is the absence of any streams—a want due primarily to the small rainfall, but intensified of course by the accumulation of sand and the consequently porous nature of the soil. To the eastward in Rájputána, as the rainfall increases, streams become more numerous and sand-hills diminish in number. In short, the sands of the Indian desert appear to have been blown from an old coast-line in the Indus valley, along the northern edge of the Ran of Kachh, and probably in the Lúni valley, by the strong south-west wind, and they remain spread over the country for the want of streams to carry them back to the sea.

§ 13. *Conclusions.*—The conclusions to which I have been led by the facts narrated in the previous paper may be thus briefly recapitulated.

1. Within very recent geological times the Ran of Kachh was part of an inlet of the sea, which certainly extended for a considerable distance up the eastern edge of the area now occupied by the Indus alluvium, and perhaps occupied the whole alluvial area of the Indus valley: it also in all probability covered a considerable tract in the Lúni basin.

2. The central portion of the desert about Jaysalmír and Bálmir was not covered by the sea, but formed either an island or a promontory. As the northern part of the desert, towards Baháwalpúr and Bikanír, has not been examined, it is uncertain whether there is any evidence of its having been covered by the sea or not.

3. The sand of the desert is mainly derived from the old sea-coast, and its transport into the interior of the country is due to the south-west wind.

